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Persistent handwriting problems are hard to predict: A longitudinal study of the development of handwriting in primary school

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ABSTRACT

Background: After one year of tuition, up to a third of primary school children show insufficient handwriting. It is unclear whether this early insufficient handwriting predicts persistent handwriting problems, because there is a dearth of studies that followed developmental trajectories longitudinally.
Aims: To describe handwriting development in primary school children longitudinally and to determine predictive positive value and sensitivity of early handwriting assessment. To analyse whether underlying abilities helps early identification of persistent handwriting problems.
Methods: 173 primary school children were yearly assessed for four years using the Concise Assessment Scale for Children's Handwriting and the Beery Buktenica developmental test of visual-motor integration.
Results: Both quality and speed of handwriting increased with years of tuition, with a pronounced increase in quality between two and three years of writing tuition. Sensitivity and positive predictive value were low. The only significant predictor of handwriting quality was handwriting quality in the previous year. For handwriting speed, no significant developmental model was revealed.
Conclusions: Quality and speed of handwriting after one year of tuition is not sufficiently predictive for distinguishing between transient insufficient handwriting and persistent handwriting problems three years later. Practitioners should hold back when referring children for remedial teaching.

What this paper adds?

In order to reveal the development of handwriting (problems) and possible predictive factors, present study longitudinally examined handwriting quality and speed and the abilities to perceptually identify forms, to produce well-controlled movements, and to visually control the movements.

Our conclusions are:

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- 87 % of the children with insufficient handwriting after 1 year of tuition improved and showed satisfactory handwriting 2–3 years later.
- Only 1 out of 10 children with insufficient handwriting at an early stage of the handwriting acquisition showed insufficient handwriting 3 years later (low positive predictive value of early assessment)
- 78 % of the children with sufficient handwriting at an early stage of the acquisition process showed good handwriting after 3 years.
- Although perceptual and motor skills (VMI) in the first year were associated with handwriting quality in the same year they were not related to the quality of handwriting in subsequent years.

1. Introduction

1.1. Typical handwriting development in children

Despite the increased use of computers, writing by hand remains one of the most important skills that children learn in primary school (Asher, 2006; Denton, Cope, & Moser, 2006; Feder & Majnemer, 2003 (Feder & Majnemer, 2007); Ratzon, Efraim, & Bart, 2007). In Western countries, several handwriting methods are used to teach handwriting in primary school, starting tuition at the age of 6 years up to 10 years (e.g., Handwriting without tears; Teach handwriting; Teach it english). In a pseudo-longitudinal study, Overvelde and Hulstijn (2011) charted handwriting development during the first three years of writing tuition in primary schools (in the Netherlands). After one year of tuition (at approximately 7 years of age) about one-third of the children was found to show satisfactory quality of writing; after two years of writing tuition (at age 8), half the children achieved a satisfactory level of handwriting, while after 3 years (at age 9), over three-quarters of the children had satisfying handwriting quality; only 6 % of the children had their handwriting rated as insufficient after three years. These results suggest that for most children early insufficient handwriting is likely to be transient and will improve with regular tuition and practice (Overvelde & Hulstijn, 2011). Yet, for a small minority of children handwriting problems turnout to be persistent.

The range of prevalence of insufficient handwriting reported in the literature varies from 6 to 33 %. This broad range is probably related to the diversity in assessment tools and age of the children across studies (Hamstra-Bletz & Blöte, 1993); Karlsdottir & Stefansson, 2002; (Feder, 2007; Overvelde & Hulstijn, 2011). Insufficient handwriting includes illegible handwriting, slow handwriting seed and/or fatigue and pain while writing (Biotteau et al., 2019; Hamstra-Bletz, de Bie, & den Brinker, 1987; Kaiser, Albaret, & Doudin, 2009; Overvelde et al., 2011; Smits-Engelsman, Niemeijer, & van Galen, 2001).

Already after one or two years of writing tuition (i.e., at the age of 6–7 years, Bosga-Stork et al., 2009), children with insufficient handwriting are often referred to a therapist. Accordingly, Biotteau et al. (2019) have suggested that occupational or paediatric physical therapy is crucial for effective improvement. Referring children to therapy, however, requires distinguishing as early as possible between children that are genuinely at risk for insufficient handwriting being permanent (i.e., handwriting that does not improve with regular tuition) and children whose handwriting problems are transient. Short-term longitudinal or cross-sectional studies failed in making a reliable distinction between transient or persistent handwriting problems (Karlsdottir & Stefansson, 2002; Overvelde & Hulstijn, 2011). To verify these observations, it is important to conduct longitudinal research that chart the developmental trajectories of handwriting in primary school children to examine sensitivity, specificity and predictivity of current handwriting tests. A longitudinal research design can also help to identify the factors related to the development of handwriting and that potentially underly persistent handwriting problems.

1.2. Prediction of persistent handwriting problems

Early prediction of handwriting problems can be grounded in assessment of handwriting quality and speed and/or on the basis of abilities that – presumably – underpin handwriting skills. The extant literature reports only one longitudinal study that followed handwriting development over a period that extended beyond two years of writing tuition. Karlsdottir and Stefansson (2002) annually assessed handwriting in over 400 primary school children between one and five year of writing tuition (i.e., Norwegian grade 1–5). They used custom-made assessments for handwriting quality and speed. The handwriting quality of three-quarter of the children was rated as sufficient (i.e., functional) after one year of writing tuition. During the second year of tuition (grade 2), handwriting quality of these children improved less to plateau after three years (i.e., grade 4). For children whose handwriting was rated as insufficient after one of year of tuition, handwriting quality also continued to improve but at slower rate than their typically developing peers. Consequently, these children ended with lower handwriting quality after four years of tuition. Importantly, however, among the children who showed insufficient handwriting after four years of writing tuition in Norwegian grade 5 (i.e., approx. 15 %), half had been tested as having insufficient handwriting in earlier grades; these were the children with persistent handwriting problems. Yet, the other children with insufficient handwriting in grade 5 were only rated as such in grade 5. Conversely, for approximately four out of five children who had shown insufficient handwriting during the first three years of tuition, the problems turned out to be transient and had disappeared after four years of tuition in grade 5.

These observations indicate that the sensitivity of the longitudinal assessment for identifying persistent handwriting problems was only 50 %. Additionally, the positive predictive value (i.e., the likelihood that a child with insufficient handwriting after one year of tuition still has insufficient handwriting after four years of tuition in grade 5) was a mere 28 %. In other words, prospective developmental pathways could not be reliably predicted based on handwriting quality after one year of handwriting tuition. While

these results imply that referral for handwriting problems early in the acquisition process involves high risk of unnecessary treatments, it is important to verify whether the low sensitivity and predictive value were not due to the particular handwriting assessment used by Karlsdottir and Stefansson (2002). The test-retest reliability of the custom-made test assessment was reported to be good. The norms, however, for distinguishing sufficient (i.e., functional) and insufficient (dysfunctional) handwriting quality were not validated, but, based "on subjective evaluations of legibility and functional speed" (Karlsdottir & Stefansson, 2002, p. 17).

Research has shown that handwriting problems can be related to problems with motor coordination and/or visuo-motor abilities (Smits-Engelsman et al., 2001; Volman, van Schendel, & Jongmans, 2006; Weintraub & Graham, 2000). That is, these studies suggest that handwriting quality may be constrained by the ability to perceptually identify forms, to produce well-controlled movements, and to visually control the movements. These abilities have been assessed by the Beery Buktenica developmental test of visual-motor integration (Beery-VMI, Duiser, Kamp van der, Ledebt, & Savelsbergh, 2014; Kaiser et al., 2009; Volman et al., 2006), which requires children to recognize geometrical forms, the ability to draw between lines, and/or the ability to copy or redraw a form, respectively. A cross-sectional study has shown that the outcomes of the Beery-VMI copy and drawing subtests correlate with handwriting quality in a group of children aged 9–12 years. However, sensitivity of the Beery-VMI for identifying handwriting problems was low (Goyen & Duff, 2005). Evidence that the visual recognition test correlates with handwriting quality is equivocal (Duiser et al., 2014). Further to this point, Karlsdottir and Stefansson (2002), showed that children's ability to copy a form after one year of tuition was positively related to handwriting quality after one year of tuition but did not relate to handwriting quality in subsequent grades. Other abilities (e.g., recognition of geometrical forms) were not assessed. In sum, although it has been shown that visuo-motor abilities relate to handwriting performance (i.e., at one instant in time), their role in long-term handwriting development has largely been neglected.

The primary aim of the current study was to examine sensitivity and predictive values of early assessment of handwriting quality in relation to persistent and transient handwriting problems years later. To this end, we longitudinally charted handwriting development between the first and the fourth year of handwriting tuition in terms of both quality and speed, using the Concise Assessment Scale for Children's Handwriting (BHK), which is widely used within Europe (Hamstra-Bletz et al., 1987; Kaiser et al., 2009; Smits-Engelsman et al., 2001). To determine the sensitivity and positive predictive value of the BHK we used the norm-based cut-off scores, and also explored how systematic adjustments in the cut-off scores differentiating sufficient from insufficient handwriting affect its prognostic value in identifying persistent handwriting problems.

The second aim was to establish whether some of the presumed underlying perceptual-motor abilities of handwriting as assessed with the Beery-VMI test could help to distinguish between children with persistent and children with transient handwriting problems. Previous studies did show cross-sectional relationships between at least some of the Beery-VMI subtests and handwriting performance (Duiser et al., 2014; Goyen & Duff, 2005; Karlsdottir & Stefansson, 2002). Yet, it is still unclear whether these subtests also predict the development of handwriting quality and speed in subsequent years.

2. Methods

2.1. Participants

Children from six primary schools in two medium sized towns in the west of the Netherlands participated in this study. The children attending these schools were predominantly from middleclass families. A total of 239 children participated over the four years, 173 of which completed all assessments. The other children missed one or more tests, because they were ill, moved to another school, were absent for other reasons or refused to participate (Fig. 1).

Handwriting quality and speed scores of the group of children who did not participate in each of the four tests did not significantly differ from other children (i.e., on the assessments they did complete). Only children that completed all test were included in the analyses. The final sample consisted of 83 boys (71 right handed) and 90 girls (81 right handed) with an average age of 7 years and 5 months during the first assessment after one year of tuition (i.e., at the beginning of grade 4). During handwriting tuition Dutch children learn to write the letter shapes, while the letter is pronounced by their teacher. Typically, the teacher demonstrates how to write the letter group wise, then children individually practice the letter shape in course books, following a set curriculum. In the Netherlands, children should be able to write in cursive handwriting after one year of handwriting tuition, which enables the use of handwriting assessment tools like the BHK.

The faculty's ethical committee approved the study, and parents of the children provided written informed consent.

2.2. Material

The Concise Assessment Scale for Children's Handwriting (BHK) was used to assess children's handwriting. The BHK requires children to copy a text within five minutes on unlined paper and assesses handwriting in terms of its quality and speed. Handwriting quality is assessed with respect to letter size and margin of the entire text (0–5 points each), and with respect to alignment, word spacing, acute turns in joints or letters, irregularities in joins, collisions of letters, inconsistent letter size, incorrect relative letter height, strange, indistinctive or corrected letterforms and unsteady writing trace in the first five lines. Children get 0 (no irregularity) or 1 point (1 or more irregularities) per line. The following cut-off norms are proposed by the test manual: 0–21 points indicates non-dysgraphic handwriting, 22–28 ambiguous and 29 points or more indicates dysgraphic handwriting.[1] Intra- and interobserver

[1] Note, the appellations 'dysgraphic', 'ambiguous' and 'not-dysgraphic', refer to the category labels used in the BHK. However, since dysgraphia is

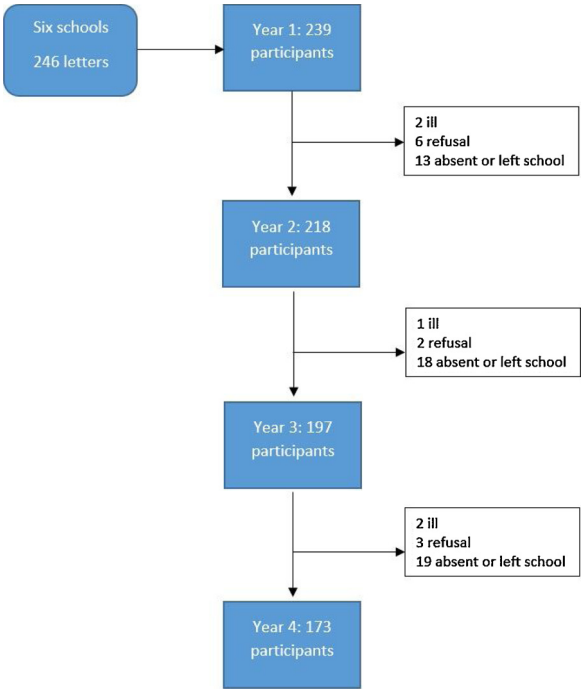

Fig. 1. Participants participation over the four years.

reliability for quality (respectively r = 0.91 and r = 0.85; e.g., (Duiser et al., 2014)) is good. Test-retest reliability is low but adequate for quality and sufficient for speed (respectively r = 0.51 and r = 0.78; (Hamstra-Bletz, 1993).

In addition, the Beery-VMI test was used to assess abilities that are presumed to underlie handwriting. The Beery-VMI is a norm-referenced test that evaluates children's ability to identify geometrical forms (i.e., visual perception or VP-test), to draw between lines (i.e., motor coordination or MC-test) and to copy forms (i.e., visual-motor integration or VMI-test). A detailed description of these assessments can be found elsewhere (e.g., Volman et al., 2006). The Beery–VMI is a norm-referenced test for people from 2 to 100 years. Test-retest coefficients were: VMI 0.88; VP 0.84 and MC .85 (Beery & Beery, 2010). The intra-rater and inter-observer agreements for each of the three subtests is high (i.e., VP, r = 1.0 and r = 0.99, respectively; MC r = 0.98 and 0.94; VMI, r = 0.89 and r = 0.84; Duiser et al., 2014).

2.3. Procedure and design

The BHK and Beery-VMI were annually administered over a period of four years between 2010 and 2013, after one to four years of tuition (in Dutch grade 4–7, corresponding to 7 through 11 years old children) and always at the start of the school year. In the Dutch school system, the first year of handwriting tuition is in Dutch grade 3. The final assessment was in grade 7. In Dutch grade 8 children are encouraged to develop their own handwriting style, frequently including both cursive and manuscript letters. This, cannot be assessed by the BHK, and hence, we report across four years of tuition. Each year, all children in the relevant grade were asked to participate, irrespective of participation in earlier years.

The tests were administered group wise in the classroom with the children sitting on standard school furniture and using their regular writing device (i.e., pencil or pen). Prior to the assessment, the children received test material (i.e., the target text, a blank sheet of paper without lines, and the three Beery-VMI test forms). The BHK was always administered first, followed by the VMI-, the VP- and the MC-subtests of the Beery-VMI (in this order, as prescribed by the Beery-VMI manual). Children received a general introduction prior to the test session, and specific instructions prior to each (sub-)test. After completion of each test, the test material was removed from the children's desks. The total duration of the tests was between 20 to 30 min.

2.4. Data analysis and statistics

Handwriting quality was measured with 13 items according to the BHK manual, resulting in total scores between zero (i.e., sufficient handwriting) and 64 (i.e., very insufficient handwriting). Handwriting speed was measured by counting the number of letters children wrote in 5 min. To assess developmental changes in handwriting, the scores for handwriting quality and speed were

(*footnote continued*)
no longer present in the DSM-V, we use the more neutral labels 'insufficient' and 'sufficient'.

submitted to two separate repeated measures ANOVA's with years of tuition (1, 2, 3 and 4 years) as within-factor. In case the sphericity assumption was violated, the Greenhouse-Geisser correction was used. As a measure for effect size, partial eta squared (η_p^2) was used, where 0.01–0.06 was interpreted as a small effect, 0.06–0.14 as a medium effect and > 0.14 as a large effect (Cohen, 1988). Post hoc analyses were performed using *t*-test with Bonferroni adjustments.

Further, to explore what factors predicted handwriting quality and speed after four years of tuition (i.e., grade 7) two separate path analyses were performed. With path analysis direct dependencies between a set of longitudinal variables can be uncovered (see Byrne, 2010; Ste-Marie, Carter, Law, Vertes, & Smith, 2015). Two models were created addressing the relationships between, on the one hand, VMI-, VP- and MC-scores for each tuition year, and on the other hand, BHK handwriting quality or speed also for each tuition year. The data were analyzed using AMOS 23.0. In the first model, the VMI-, VP-, MC-scores were related to the BHK for each tuition year separately. Besides that, all BHK-, VMI-, VP-, MC-scores were linearly related to the BHK scores for all subsequent tuition years (i.e., BHK tuition year 2 with year 3, 4 and 5 and so on). A similar approach was taken with respect to speed. Based on the evaluation of fit indices for the comparative fit index (CFI), the root mean square error of approximation (RMSEA) and the chi squared ($\chi 2$) likelihood ratio statistic (Byrne, 2010) different models were created. Fit indices were deemed to indicate good model fit if: CFI values ≥ 0.90, RMSEA values ≤ 0.06, $\chi 2$ not significant, and $\chi 2/df < 3.00$ (Byrne, 2010). Only the model(s) with appropriate fit indices will be presented.

Finally, the raw BHK quality scores were converted into the three categories according to norm-based cut-off values in the manual: i.e., insufficient handwriting for 29 points or more, ambiguous handwriting for 22–28 points, and sufficient handwriting for 21 points and less. The sensitivity, specificity and positive predictive value of the test-scores were established using the percentage of children classified with insufficient handwriting quality or with sufficient handwriting quality after one and four years of handwriting tuition.

3. Results

3.1. Developmental changes

In general, handwriting quality increased with years of tuition (Fig. 1a). In grade 5 most children wrote sufficient (n = 131; 75.7 %) A repeated measures ANOVA showed a significant effect for years of tuition on BHK quality scores, $F(2.554, 439.221) = 74.2$, $p < 0.001$, $\eta_p^2 = 0.30$). Post hoc comparisons indicated that the only significant increases occurred between two and three years of tuition (Fig. 2a). A repeated measures ANOVA also revealed significant differences for years of tuition with respect to speed, $F(2.737, 470.688) = 524.9$, $p < 0.001$, $\eta^2 = 0.75$). Post hoc comparisons indicated that with each additional year of tuition children wrote significantly faster (Fig. 2b).

3.2. Predicting persistent and transient handwriting problems

First, each child in each year was classified according to raw BHK quality scores as insufficient, ambiguous and sufficient (Fig. 3a). The distribution of children over those three categories changed over the years: after one and two years of tuition the children were approximately equally distributed across the three categories while thereafter, most children were classified as sufficient.

After four years of tuition, only nine children showed insufficient handwriting (8 boys, 1 girl; Fig. 3b). Among these children, three boys had shown insufficient handwriting quality in all three foregoing years; two boys had shown ambiguous handwriting after one year of handwriting tuition, insufficient handwriting in subsequent years. The remaining three boys showed variable handwriting

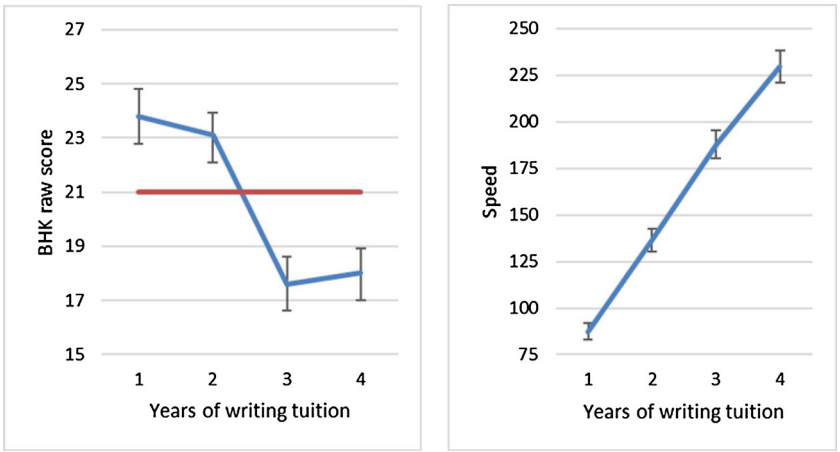

Fig. 2. Mean BHK scores (95 % CI standard error) for quality (a) and speed (b) as a function of years of tuition. Horizontal red line in (a) indicates the cut-off score between sufficient and ambiguous handwriting as indicated in the BHK. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

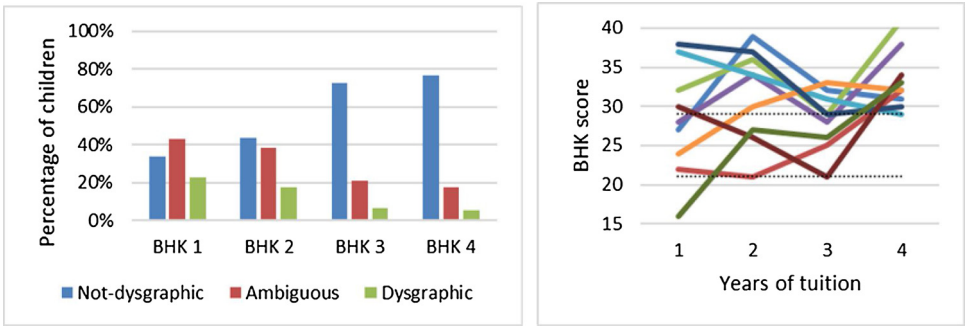

Fig. 3. Handwriting quality after four years of tuition, (a) percentage of children per category per grade and (b) handwriting quality scores across the four years of tuition of the children who showed insufficient handwriting. Dashed lines indicate the cut-off scores between sufficient and ambiguous handwriting (i.e., at score 21) and between ambiguous and insufficient (i.e., at score 29).

performances across the four years of tuition, with quality scores fluctuating between sufficient and insufficient (Fig. 3b, green, light and dark brown lines). Finally, the one girl within this group showed a decrease in handwriting quality over the years (i.e., after one year of tuition her handwriting was rated as sufficient, while it was rated ambiguous in the two years thereafter, and insufficient after four years).

Handwriting quality appeared relatively instable across the four years. That is, only in 19.1 % of the children (n = 34; 13 boys) the handwriting quality was rated in the same BHK-category in each of four assessments. In 19.7 % of the children the handwriting ratings stayed the same in the final three years (n = 35; 15 boys), whereas 32.6 % of the children (n = 58; 28 boys), had the same handwriting quality rating after three and four years of tuition. Handwriting pathways appeared to be fluctuating between BHK-categories in 28.6 % of the children (n = 46; 20 boys) (Fig. 4).

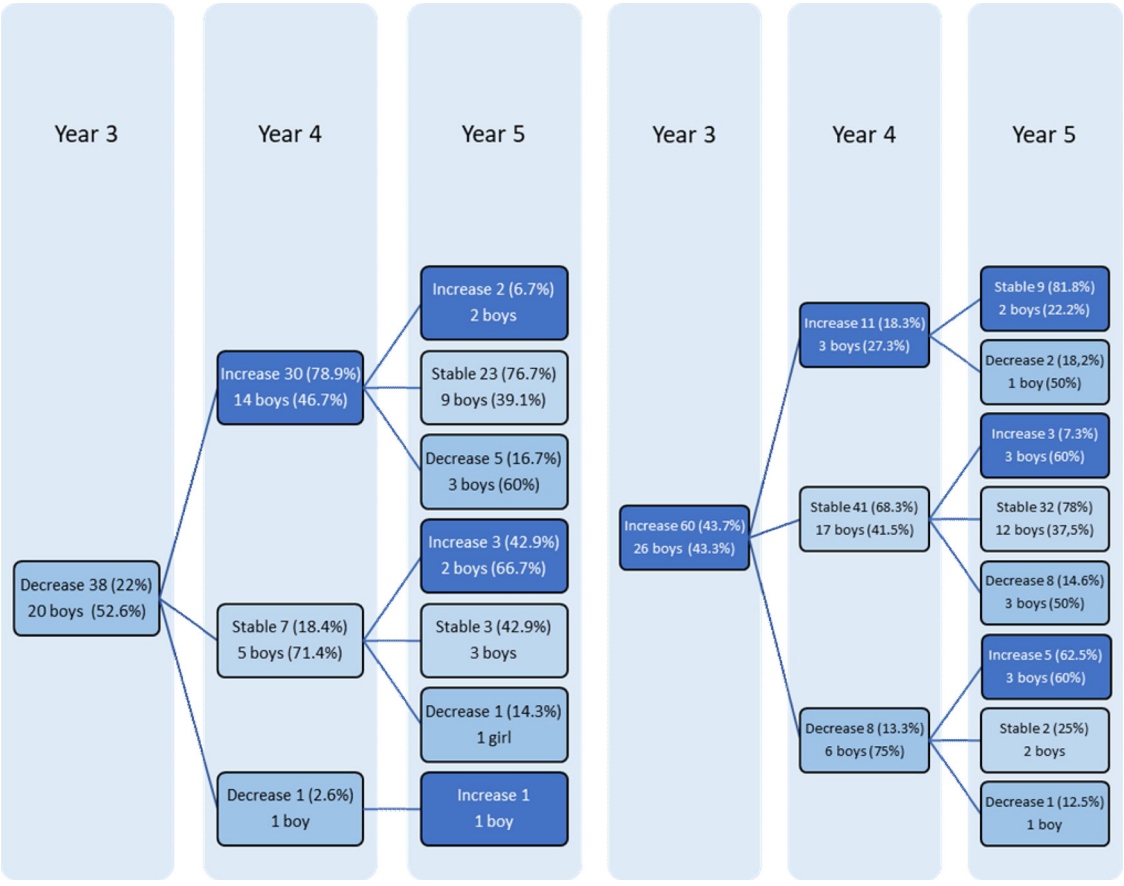

Fig. 4. Changes in handwriting quality over the years, number of children.

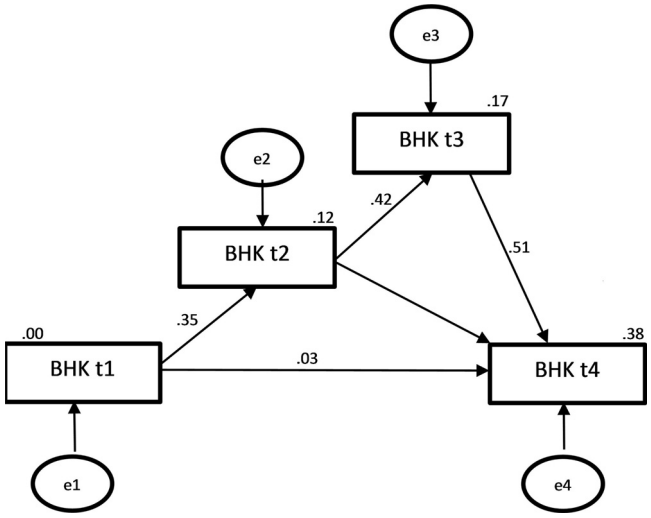

Fig. 5. Model for the longitudinal development of handwriting quality. The numbers above accompanying the BHK raw scores represent the explained variance by the model. The numbers accompanying the arrows are standard regression coefficients.

3.3. Longitudinal development

Separate path analyses were performed for BHK quality scores and speed. The first path analysis, which addressed dependencies between the BHK quality scores and the scores for the Beery-VMI subtests, showed that none of the created models with the Beery-VMI subtest had appropriate fit indices. This means that the VP, MC and VMI, despite showing significant individual correlations with handwriting quality scores within the same grade (VMI between $r = -0.171$ and $r = -0.336$, VP between zero and $r = -0.198$, and MC between -0.251 and -0.473), did not contribute to a developmental model of handwriting quality in subsequent years.

A longitudinal model based on handwriting quality showed a good fit ($\chi 2(1) = 1.553$, $p = 0.213$, CFI = 0.99, RMSEA = 0.052, and $\chi 2/df = 1.553$; Fig. 5). The quality of handwriting after four years of tuition was positively related to the quality after three years of tuition ($\beta = 0.51$, $p < 0.001$). In turn, the quality of handwriting after three years of tuition was positively related to quality after two years of tuition ($\beta = 0.42$, $p < 0.001$), which was related to quality after one year of tuition ($\beta = 0.35$, $p < 0.001$). This model explained 38 % of the quality of handwriting after four years of tuition (Fig. 5). All other paths in the model failed to reach significance (p's > 0.05).

The second path analysis addressed the dependencies between the handwriting speed scores and the scores for the Beery-VMI subtests. None of the created models with the Beery-VMI subtests had appropriate fit indices. This means that the VP, MC and VMI did not contribute to a developmental model of handwriting speed. Also, a longitudinal model based on handwriting speed did not show a good fit ($\chi 2(1) = 6.122$, $p = 0.013$, CFI = 0.967, RMSEA = 0.172, and $\chi 2/df = 6.122$). There were, however, significant but weak correlations for speed between the different years of tuition, ranging from $r = 0.237$ between 1 and 4 years of writing tuition and $r = 0.580$ between 3 and 4 years of tuition (all p's < 0.001).

3.4. Sensitivity, specificity and predictive values

Sensitivity, specificity and predictive values were calculated by using the cut-off between ambiguous and insufficient handwriting as indicated in the BHK manual (corresponding to the score of 29). The positive predictive value (i.e., the likelihood that a child with insufficient handwriting after one year of tuition also had insufficient handwriting after four years) was 10 %. The sensitivity (i.e., the likelihood that a child with insufficient handwriting after four years of tuition had insufficient handwriting after the first year of tuition) was 44 %. The specificity (i.e., the probability that a child rated as having sufficient handwriting after four years of tuition was also rated as sufficient after one year of tuition) was 78 %. And finally, the negative predictive value (i.e., the likelihood that a child with sufficient handwriting after one year of tuition was also rated as sufficient after four years) was 96 %.

4. Discussion

We aimed to chart handwriting development in primary school during the first four years of writing tuition to examine whether insufficient writing after one year of tuition does predict persistent handwriting problems later during development. Previous research suggested that early handwriting quality assessment had poor sensitivity and positive predictive value for handwriting quality four years later (Karlsdottir & Stefansson, 2002). The present study tried to further bolster these observations using widely used and standardized tools for the assessment of handwriting and the underpinning perceptual-motor abilities.

The results revealed an average increase in handwriting quality and speed across the first four years of writing tuition, with a particularly significant gain in handwriting quality after two years of writing tuition, resembling the developmental differences that

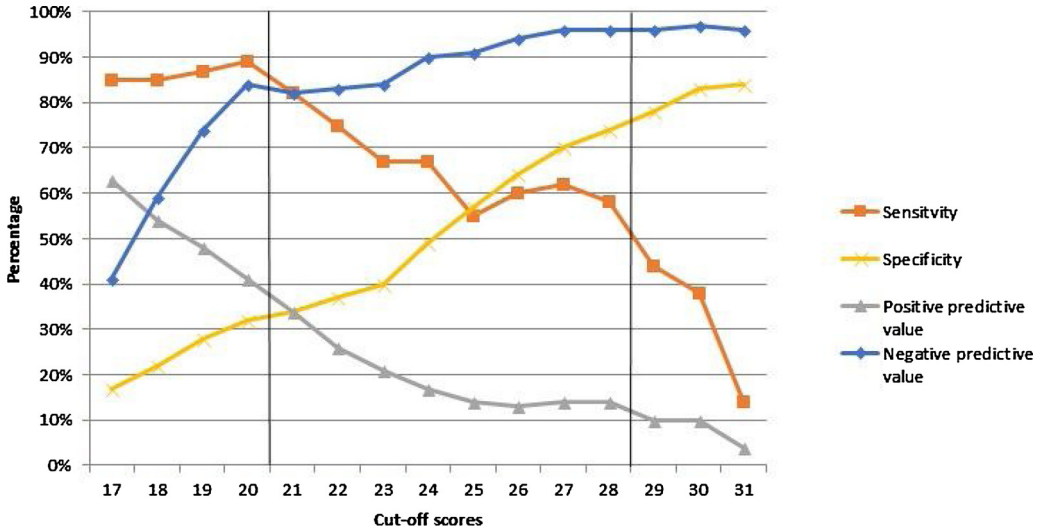

Fig. 6. Sensitivity, positive and negative predictive values and specificity as a function of cut-off point. The two vertical lines indicate the cut-off scores between dysgraphic and ambiguous (between 28 and 29) and ambiguous and not-dysgraphic (between 21 and 22) according to the BHK manual.

were previously reported by Overvelde and Hulstijn (2011). For handwriting speed, the improvement increased more gradually across the four years. Accordingly, the number of children categorized with insufficient handwriting strongly decreased from the second to third year of tuition and then stabilized, resulting in approximately 5 % of children (n = 9) with insufficient handwriting after four years of tuition. Importantly, the present data show that the vast majority of children (87 %) who had shown insufficient handwriting after one year of tuition improved had caught up after four years of tuition and handwriting experience. Their early insufficiencies turned out to be transient.

The children that showed insufficient handwriting after four years of writing tuition potentially are children with persistent insufficient handwriting, that is, handwriting problems. Yet, a closer inspection of the individual developmental trajectories of these nine children showed a large variability in handwriting quality across the four years (Fig. 6b). Specifically, only three out of these nine children consistently showed insufficient handwriting across the four years. Individual developmental profiles of the handwriting quality scores across the four years revealed that handwriting development is often not improving gradually, and sometimes even showed regressions (Fig. 6). This variability in developmental profiles resulted in low positive predictive value and sensitivity, and complicating the early identification of children that are at risk of developing persistent insufficient handwriting. The outcomes of the path analysis, showing that handwriting quality (and to a lesser extent also speed) at a given year is best predicted by the quality of the preceding year, underline the poor prognostic value of early handwriting assessment for identifying later handwriting problems. The low positive predictive value and poor sensitivity are in line with the data reported by Karlsdottir and Stefansson (2002). Based on the present data we suggest that previous and actual results reveal that the low predictability is an inherent characteristic of the variable development trajectory of handwriting and not merely the result of unreliable assessment tools.

The prediction of handwriting quality after four years was not strengthened by adding perceptual-motor abilities into the prediction model. The path analysis showed that the abilities to copy, trace and recognize forms as assessed with the Beery-VMI did only correlate to current handwriting quality, and did not contribute to the prediction of handwriting quality later in development. The significant correlations between the Beery-VMI subtests and handwriting quality within a year replicate previous cross-sectional studies reporting significant associations (Duiser et al., 2014; Kaiser et al., 2009; Volman et al., 2006). In the only study that did look at predictions across years, Goyen and Duff (2005) reported that the sensitivity of the Beery-VMI in relation to handwriting quality was low (34 %). This is in line with the low positive value and sensitivity in the current study. Taken together, these results indicate that although the perceptual-motor abilities measured in the Beery-VMI provide an indication of current handwriting performance, they do not predict the development of handwriting over a period of 3–4 years.

Typically, the amount of teacher-directed tuition for handwriting will have decreased across the four years in which we followed the children. This means that self-regulation becomes increasingly important for improvement (and perhaps maintenance) of handwriting quality. Especially, self-efficacy and motivation have been shown to be important determinants of learning and development, also for motor skills (e.g., Kitsantas, Zimmerman, & Cleary, 2000; Ste-Marie et al., 2015). Future research monitors should therefore monitor these self-regulatory processes, also because current abilities to copy, trace and recognize forms may directly affect self-efficacy and motivation.

4.1. Limitations and implications

After four years of writing tuition nine of the 173 children had insufficient handwriting (5 %). The low prevalence of insufficient

handwriting may have adversely influenced the positive predictive value. When we lowering the threshold for insufficient handwriting quality, both sensitivity and positive predictive value increase. But, with a less conservative cut-off for insufficient handwriting, the test's specificity would decrease. Hence, if these lowered thresholds were used, then therapists would risk overtreatment of children without handwriting problems; which obviously does not offer a genuine solution. However, therapists should be aware that with the present norm values, the BHK does not allow to identify children who develop handwriting problems after one or two years of writing tuition While the relative low test-retest reliability of the BHK for handwriting quality (Hamstra-Bletz, 1993) has to be considered when interpreting the results, test-retest reliability for handwriting speed is sufficient (Hamstra-Bletz, 1993) and intra- and inter-observer reliability scores for quality are good (Duiser et al., 2014; Jongmans, Linthorst-Bakker, Westenberg, & Smits-Engelsman, 2003). Accordingly, rather than the BHK assessment falling short, we are inclined to argue that low test-retest reliability reflects the inherent instability of children's handwriting performance (see also Hamstra-Bletz, 1993). Clearly, this suggestion needs to be substantiated in further research. This been said, therapists should be cautious to use the BHK for the early identification of children with persistent handwriting problems. It seems warranted to hold back and limit the use of the BHK to verify current handwriting quality and speed, if regular schoolwork or teacher suggests insufficient writing. Besides that, it is advisable to compare the handwriting product produced during the BHK with actual schoolwork, to rule out the instability of children's handwriting.

Despite the obvious practical problems in terms of feasibility, for further research, it is advisable to increase sample size, such that the prevalence of children with handwriting problems after four years of handwriting tuition is increased.

4.2. Conclusion

Handwriting quality after one year of tuition did not predict handwriting quality after four years of tuition. Most of the children with insufficient handwriting after one year of tuition did show sufficient handwriting three years later. Only 10 % of children with insufficient handwriting after one year of tuition showed insufficient handwriting three years later. Most children with sufficient handwriting at an early stage of the acquisition process showed good handwriting after three years. Furthermore, perceptual and motor abilities in the first year did not predict the quality of handwriting three years later.

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This statement is signed by all the authors

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Declaration of Competing Interest

None.

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